

JCAA/JG-PP Lead-Free Solder Testing for High-Reliability Applications

Test Vehicle Assembly

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BAE SYSTEMS

**Port Canaveral, FL
April 4, 2006**

Presentation Outline

- **DESCRIPTION OF TEST VEHICLES:**
 - Alloys
 - Components
 - Types
- **ASSEMBLY DETAILS:**
 - Process Flow
 - Profiles
 - Lessons learned
- **RESULTS**
- **CONCLUSIONS**

Objective

The objective of this presentation is to provide the assembly details for the JCAA/JG-PP Joint Test Protocol (JTP) test vehicles.

Lead-Free Solder Alloys

- Tin-silver-copper ($95.5\text{Sn}3.9\text{Ag}0.6\text{Cu}$ or **SAC**) - wave, reflow and hand soldering.
- Tin-silver-copper-bismuth ($92.3\text{Sn}3.4\text{Ag}1.0\text{Cu}3.3\text{Bi}$ or **SACB**) - reflow and hand soldering.
- Tin-copper (stabilized) ($99.3\text{Sn}0.7\text{Cu}0.05\text{Ni}$ or **SnCu**) - wave and hand soldering.

Solder and Flux

Material	Wave Soldering	Reflow Soldering	Hand Soldering
Sn0.7Cu (stabilized)	X	N/A	Flux Cored Solder RMA (No Clean)
Flux	VOC Free No Clean Flux	N/A	R ROL0 Tacky Flux
Sn3.9Ag0.6Cu	Sn3.5Ag.7Cu	X	Flux Cored Solder RMA
Flux	VOC Free No Clean Flux	ROL1	R ROL0 Tacky Flux
Sn3.4Ag1Cu3.3Bi	N/A	X	0.010 Dia. Wire
Flux	N/A	No Clean (RMA)	R ROL0 Tacky Flux
Sn37Pb	X	X	Flux Cored Solder RMA
Flux	Type ORM0	ROL0	ORL0 ROL0 Tacky Flux

The recommended flux of each solder manufacturer was used.

Component Types and Finishes

COMPONENT TYPE	COMPONENT FINISH
CLCC-20	SnPb
	SAC
	SACB
PLCC-20	Sn
TSOP-50	SnPb
	SnCu
TQFP-144	Sn
TQFP-208	NiPdAu
BGA-225	SnPb
	SAC
DIP-20	Sn
	NiPdAu
0402Cap	Sn
0805Cap	Sn
1206Cap	Sn
1206Res	Sn

Components-Secondary Test Vehicle

COMPONENT TYPE	COMPONENT FINISH
Hybrids #934266-501B	SnPb
	SAC
	SACB
CSPs A-CABGA100-.8mm-10mm-DC	SnPb
	SAC

JCAA/JG-PP Primary Test Vehicles

SN	Type	Circuit Card	Reflow Solder	Wave Solder
1-41	"Manufactured-Control"	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SnPb	SnPb
72-110	"Manufactured-SAC"	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SAC	SAC
111-149	"Manufactured-SACB"	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SACB	SnCu
42-71	"Rework-Control"	$T_g \sim 140^\circ\text{C}$, GF, IPC-4101/21 SnPb HASL	SnPb	SnPb
150-177	"Rework- SAC"	$T_g \sim 140^\circ\text{C}$, GF, IPC-4101/21 SnPb HASL	SnPb	SnPb
178-205	"Rework- SACB"	$T_g \sim 140^\circ\text{C}$, GF, IPC-4101/21 SnPb HASL	SnPb	SnPb

JCAA/JG-PP Secondary Test Vehicles

Type	Circuit Card	Reflow Solder	Wave Solder
“Hybrid- Control”	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SnPb	SnPb
“Hybrid- SAC”	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SAC	SAC
“Hybrid- SACB”	$T_g \sim 170^\circ\text{C}$, GF, IPC-4101/26 Immersion Ag	SACB	SnCu

Test Vehicles

WB

14.5"X 9"X 0.09", 6 layers

Immersion silver, $T_g \sim 170^\circ\text{C}$, FR4 per IPC-4101/26

SnPb HASL, $T_g \sim 140^\circ\text{C}$, GF (rework), FR4 per IPC-4101/21

Materials

Sn3.9Ag0.6Cu (SAC) for reflow and wave soldering

Sn3.4Ag1.0Cu3.3Bi (SACB) for reflow soldering

Sn0.7Cu0.05Ni (SNIC) for wave soldering

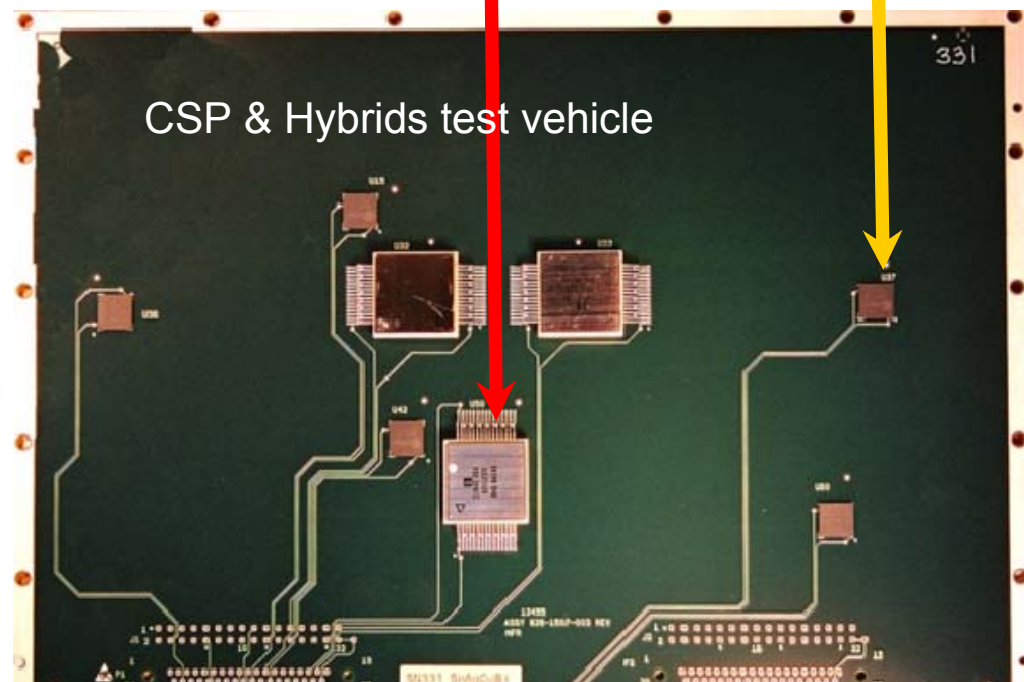
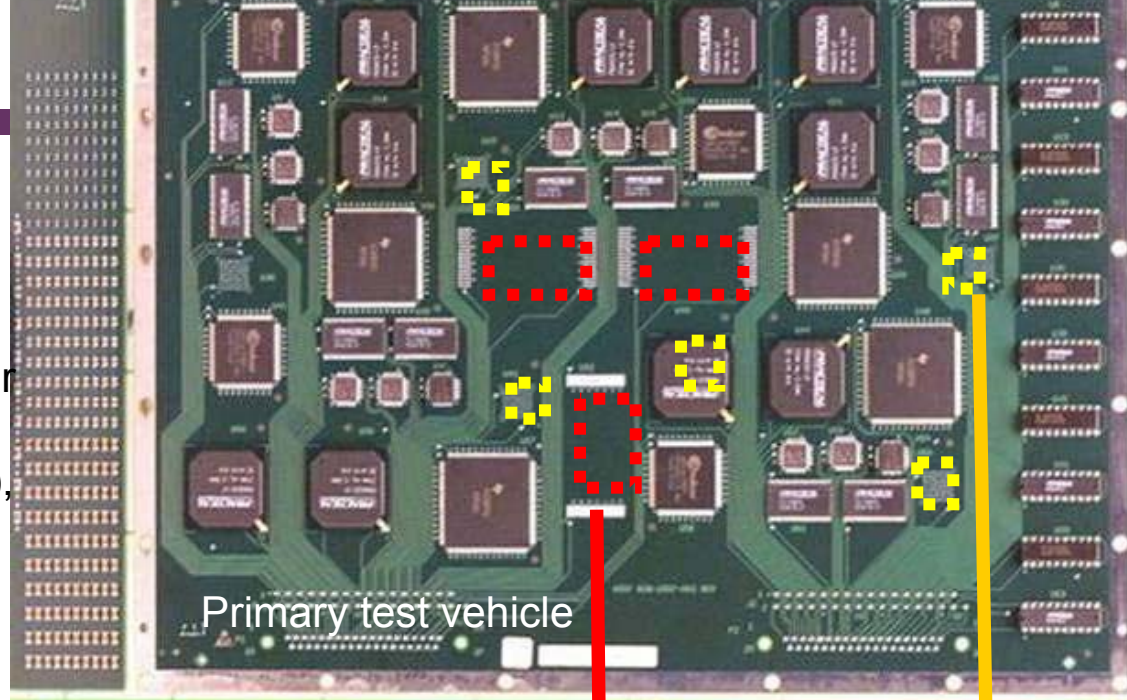
Sn37Pb (SnPb) for reflow and wave soldering

Assemblies

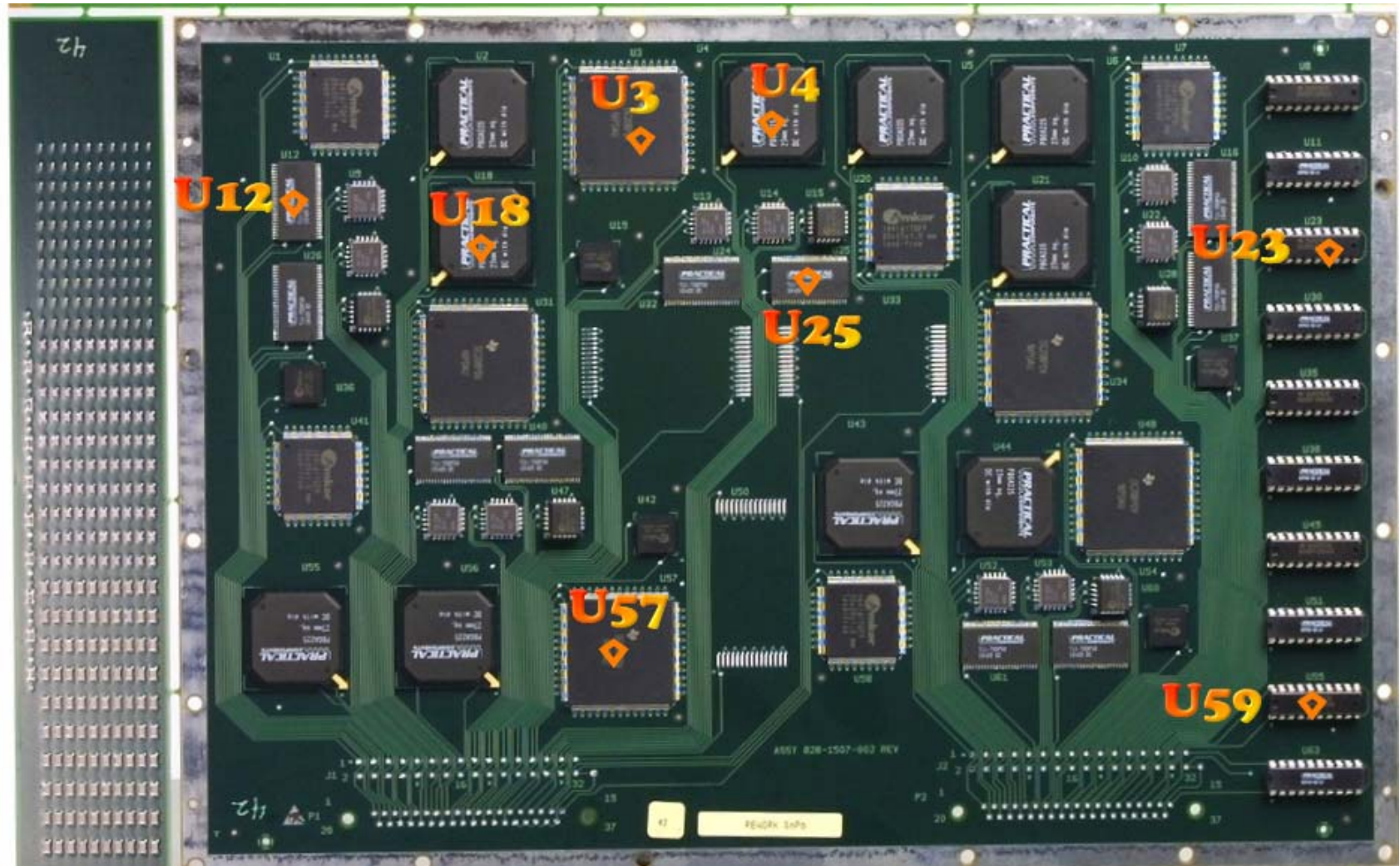
119 Manufactured

89 Reworked

30 CSP and Hybrid



Rework Test Vehicle

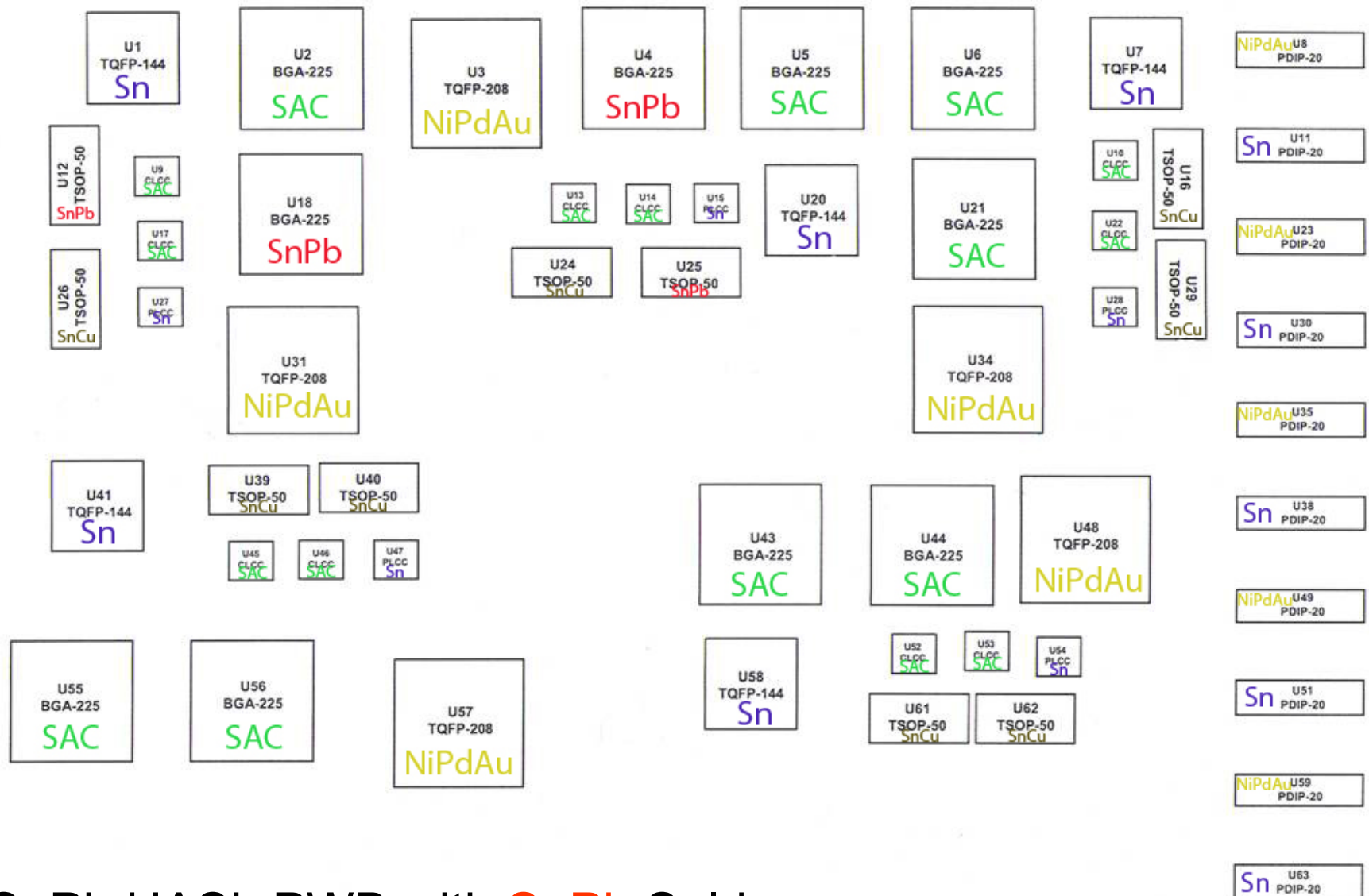


“Rework-SAC & SACB” Test Vehicles

SnPb solder initially; reworked with SAC, SACB, or SnCu solder

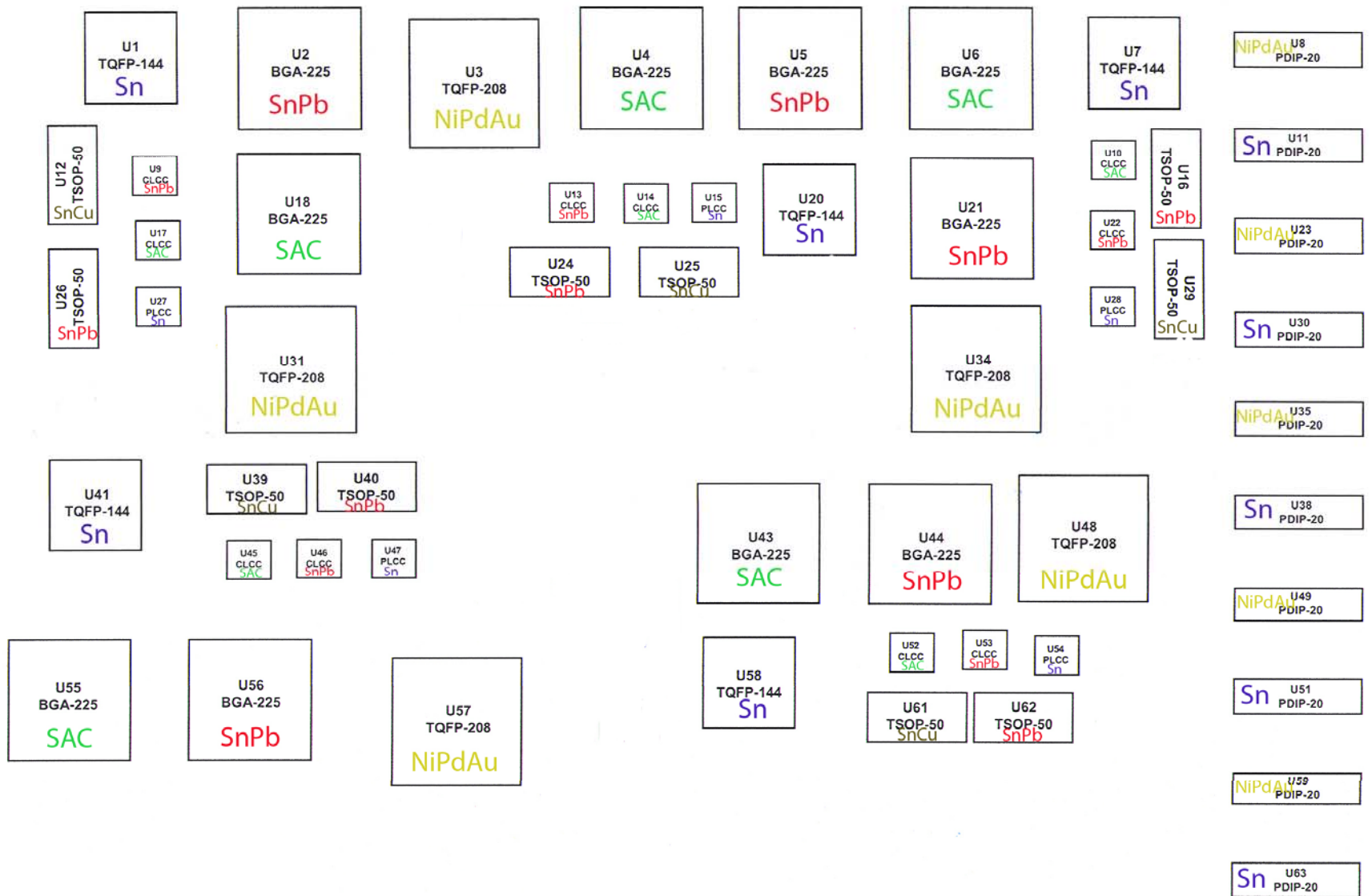
Location	Part Number	Qty Per Board	Part Finish Before Rework	Replacement Part Finish
U25	TSOP-50	1	SnPb	SnCu
U12	TSOP-50	1	SnPb	SnCu
U57	TQFP-208	1	NiPdAu	NiPdAu
U3	TQFP-208	1	NiPdAu	NiPdAu
U18	BGA-225	1	SnPb	SAC
U4	BGA-225	1	SnPb	SAC
U59	DIP-20	1	NiPdAu	NiPdAu
U23	DIP-20	1	NiPdAu	NiPdAu

"Rework-SAC" Test Vehicles



SnPb HASL PWB with SnPb Solder

"Manufactured-SAC" Test Vehicle

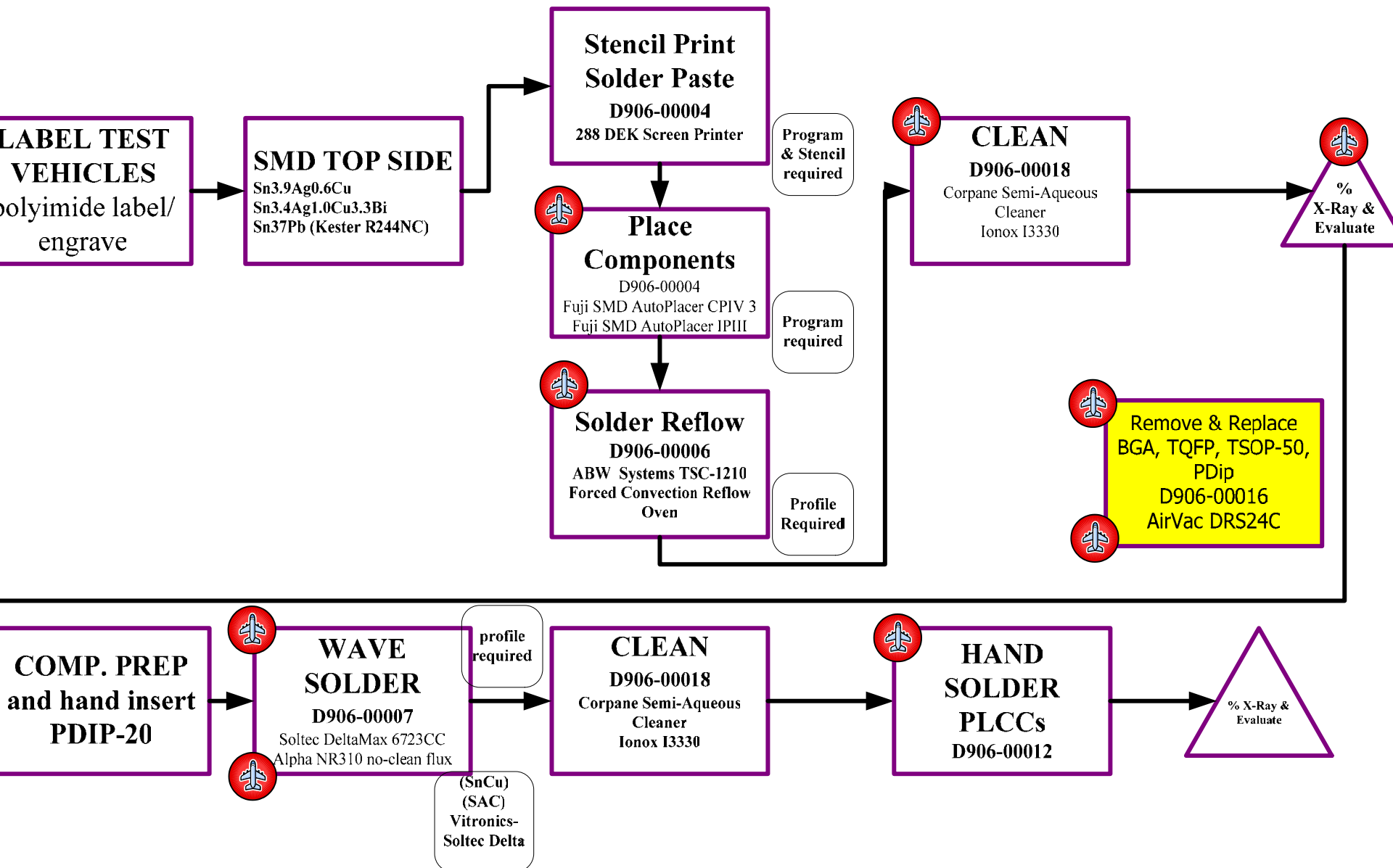


Immersion Ag PWB with **SAC** Solder

Assembly Notes

- Marking with paint dots was required to differentiate between surface finishes.
- All PLCCs were hand soldered with either SnPb, SAC, or SACB solder.
- Nitrogen was not used during reflow.
- Pb-Free wave solder with SnCu and SAC was performed at Vitronics-Soltec in New Hampshire.
- After wave solder at Vitronics, the assemblies were cleaned at Kyzen in New Hampshire.
- Solder touch-up was performed with either SnPb, SAC, SACB or SnCu solder.
- BGA rework was performed using tacky flux.
- Production traveler was used for serial number documentation.

Assembly Flow



Assembly Reflow Profiles

Standard SnPb Profile

Preheat = ~ 120 seconds

140-183°C

Peak temperature = 225°C

Time above reflow = 60-90

sec

Ramp Rate = 2-3 °C/sec

Lead-Free Profile

Preheat = 60-120 seconds

150-190°C

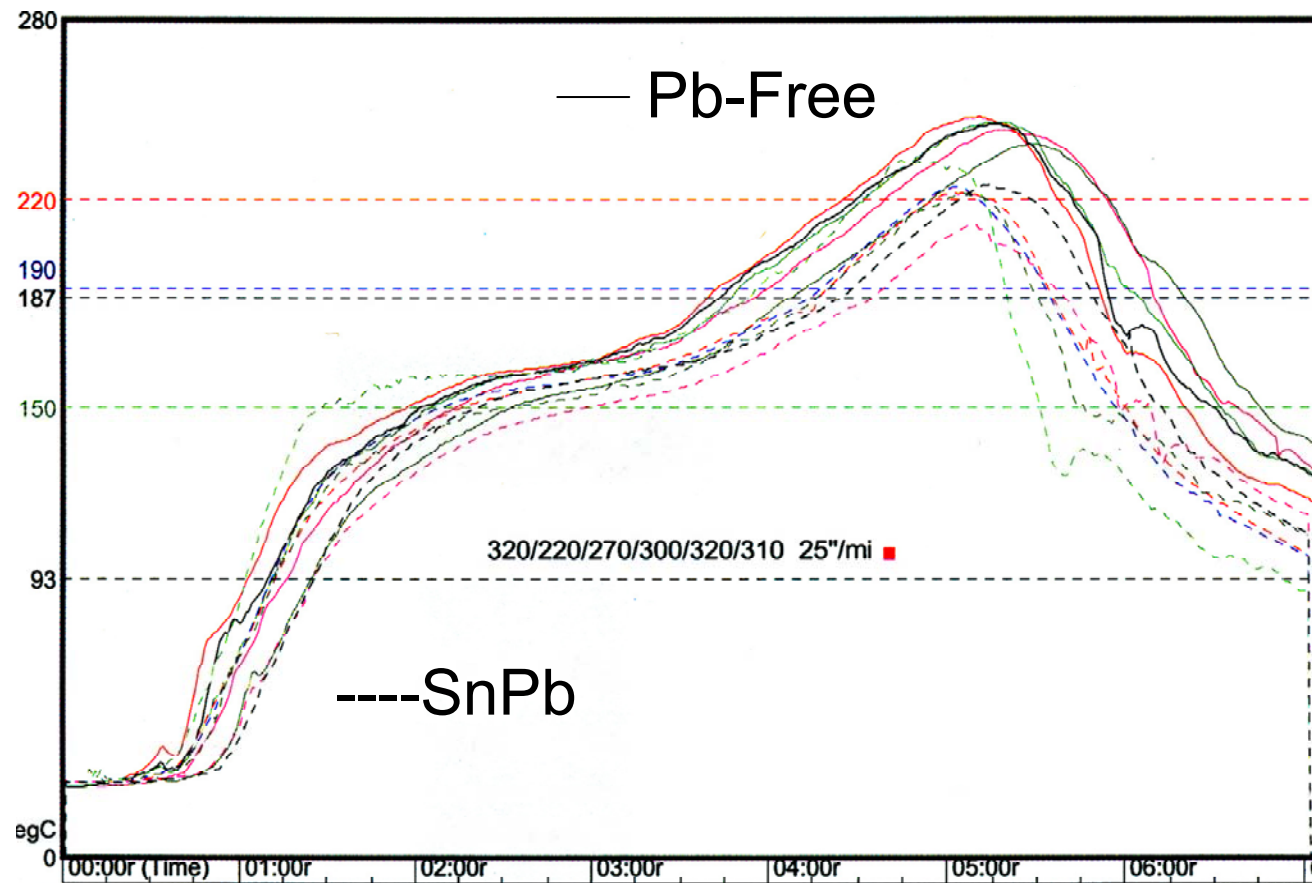
Peak temperature target =

233°C

Time above reflow:

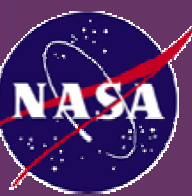
20 seconds above 230°C

30-90 seconds above 220°C



Lessons Learned

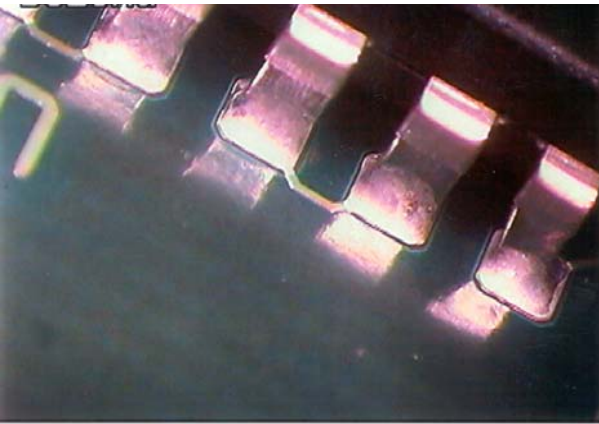
- Reflow and wave soldering resulted in a decrease in the processing window and flux became an important parameter.
- Hand soldering is similar to SnPb after a lot of practice (learning curve).
- Additional cleaning was required after rework.
- Quality inspection yielded varied results; additional training is required.
- Smaller (0.37"X 0.37") polyimide labels did not withstand Pb-free wave soldering.
- Parts control is critical during the RoHS transition.



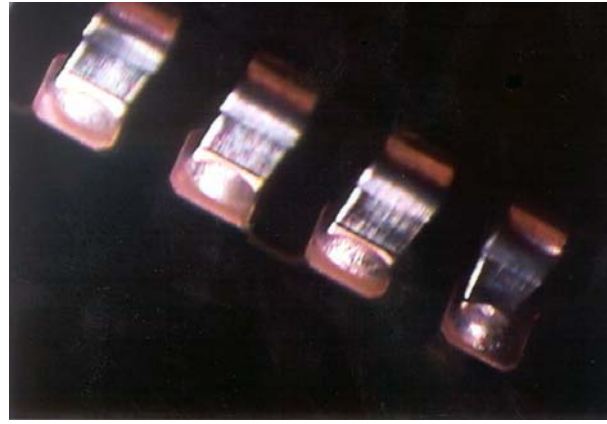
Results

Comparison of NiPdAu DIPs

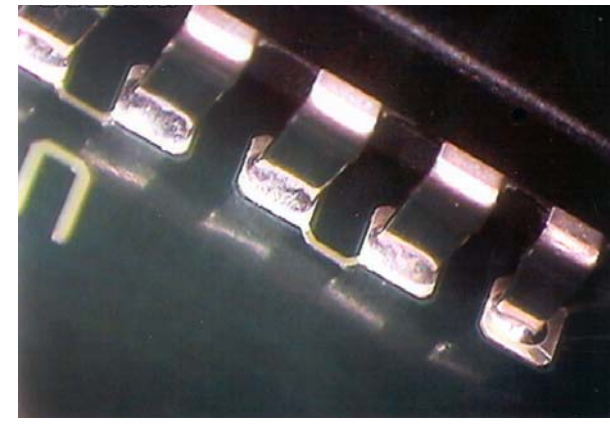
Wave soldered with SnPb, SnCu, or SAC



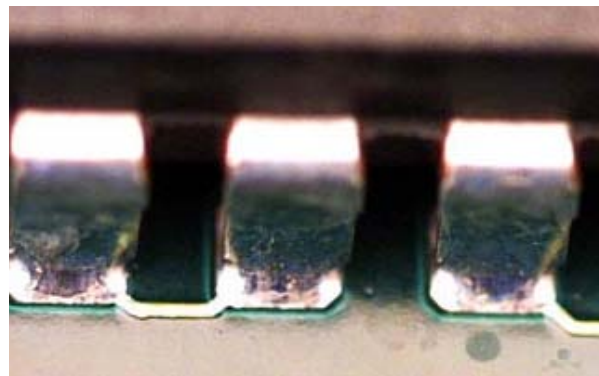
SN10: U35 with SnPb



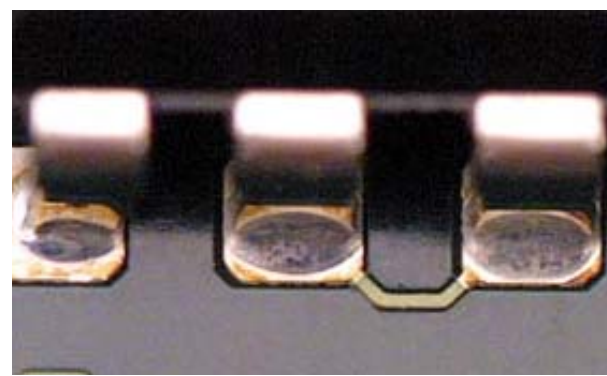
SN121: U35 with SnCu



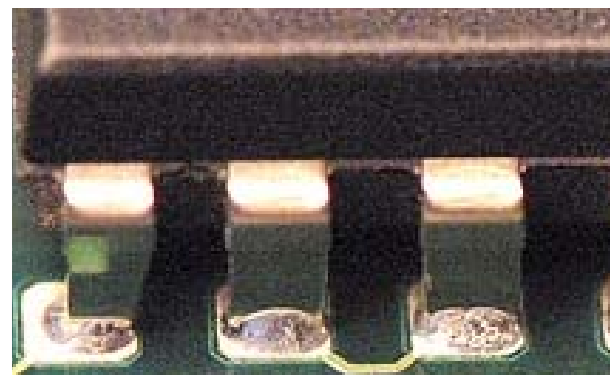
SN80: U35 with SAC



SN41: U59 with SnPb



SN138: U59 with SnCu

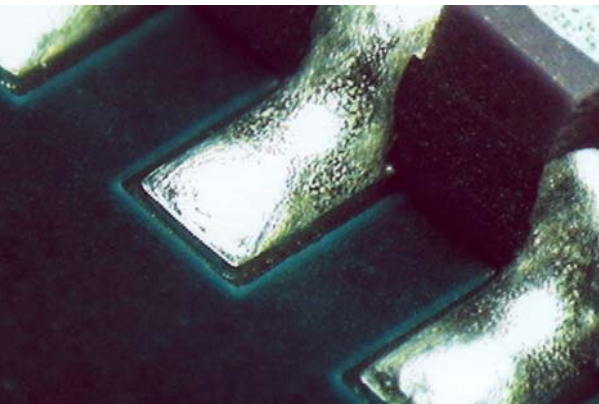


SN110: U59 with SAC

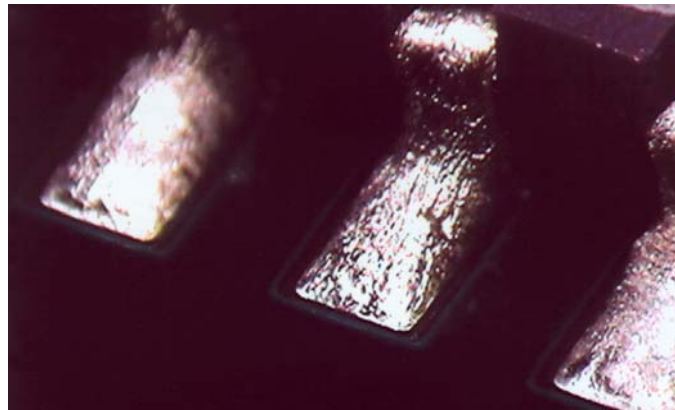
Immersion Ag PWB

Comparison of different surface finish CLCCs

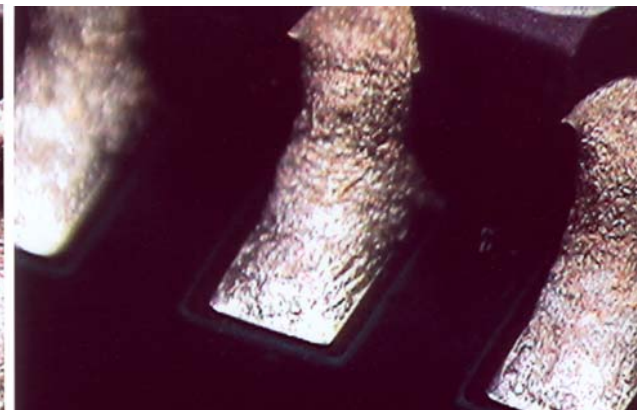
Soldered with SnPb



SN44 U17
SnPb surface finish



SN156 U17
SAC surface finish



SN182 U17
SACB surface finish

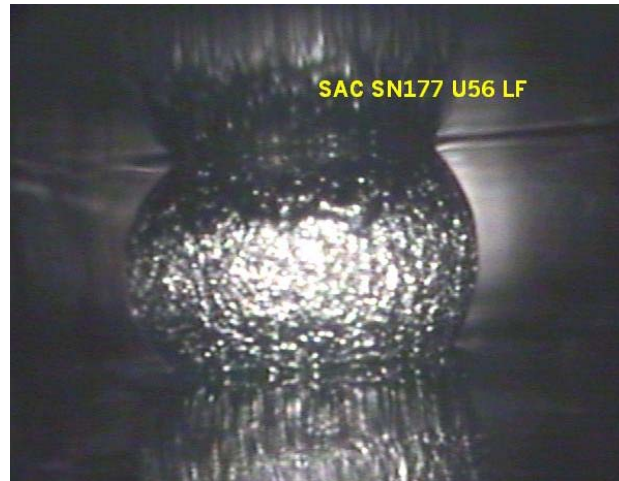
SnPb HASL PWB

Comparison of BGAs

Soldered with SnPb Solder and reflow profile



SN44 "Rework-SnPb"
SnPb BGA: SnPb solder



SN177 "Rework-SAC"
SAC BGA: SnPb solder

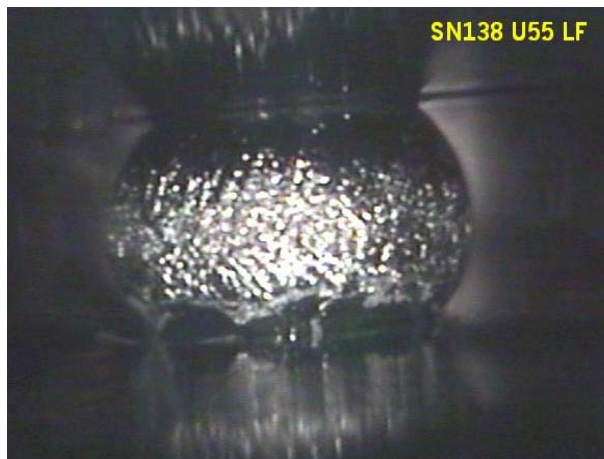
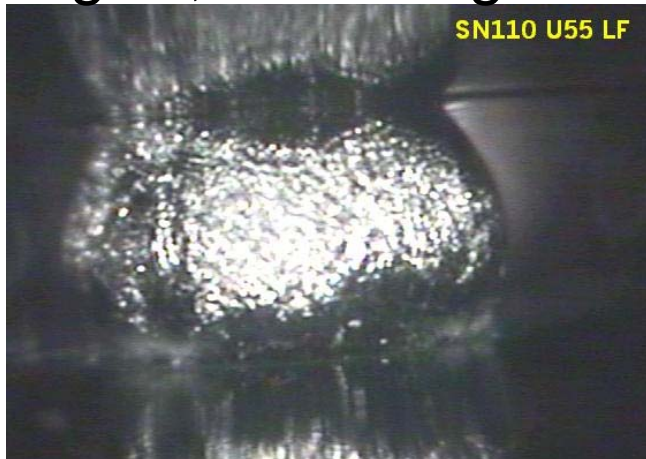


SN205 "Rework-SACB"
SAC BGA: SnPb solder

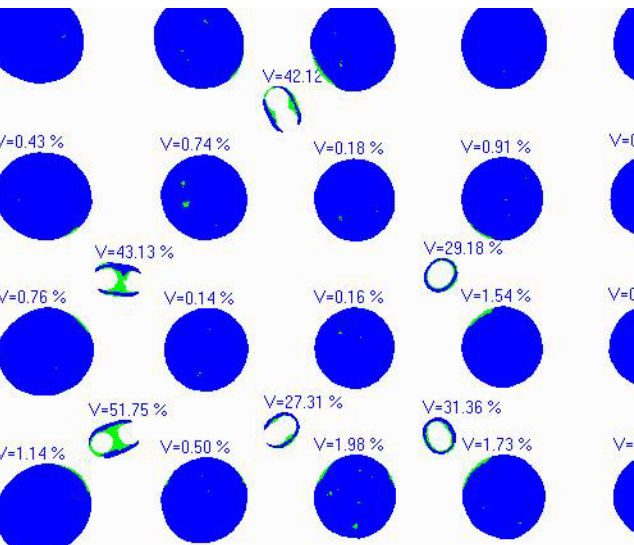
SnPb HASL PWB

BGA comparison

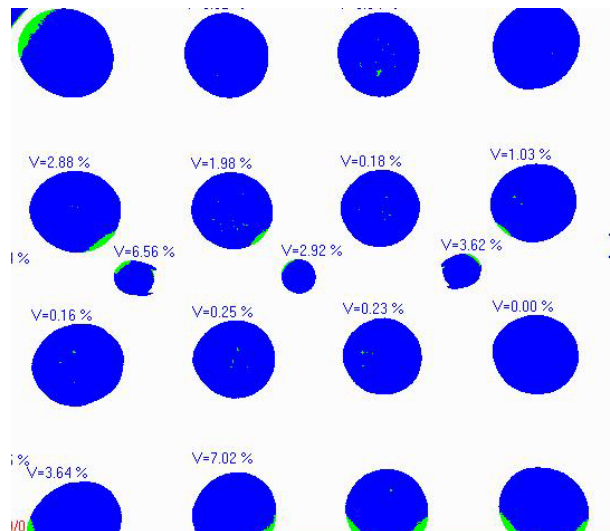
Soldered with SnPb, SnAgCu, and SnAgCuBi



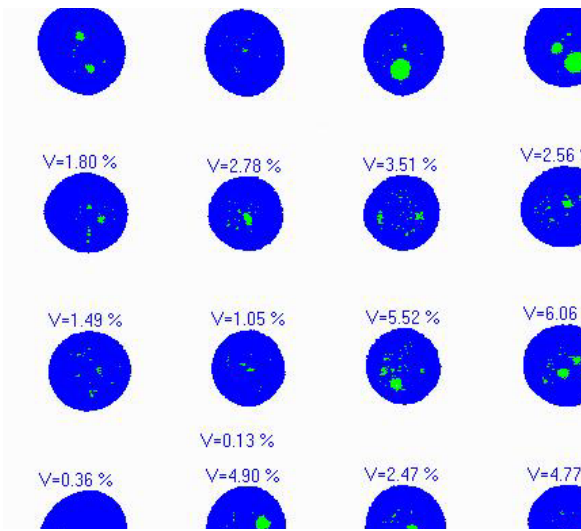
SnPb “Rework-Control”
SnPb solder/SnPb BGA



“Manufactured-SAC”
SAC solder/SAC BGA



“Manufactured- SACB”
SACB solder/SAC BGA



0.36-12.29 void percent

SIR and EMR Test Vehicles

SIR

- 46 IPC-B-24 boards (SIR)
- IPC-TM-650 Method 2.6.3.3
 - 6 boards with SAC reflow solder alloy and flux
 - 6 boards with SACB reflow solder alloy and flux
 - 6 boards with SnPb reflow solder alloy and flux
 - 6 boards with SnCu wave solder alloy and flux
 - 6 boards with SAC wave solder alloy and flux
 - 6 boards with SnPb wave solder alloy and flux
 - 5 boards with bare copper finish, no solder paste, only processed through cleaning procedures
 - 5 Boards with bare copper finish, no solder paste, passed through reflow and wave solder machines then cleaned

EMR

- 46 IPC-B-25A boards “D-comb pattern”
- IPC-TM-650 Method 2.6.14.1

Conclusions

- Assembly of high-performance electronics using Pb-free solder alloys is possible without a total retrofit of the modern factory.
- Some control of equipment may be necessary where concern for contamination from a previous SnPb process exists, such as the wave solder pot.
- Higher processing temperatures impact the soldering process window (e.g., dwell times, flux chemistry), component moisture sensitivity controls, and solder flux residue removal.
- Significant resources will be required for component configuration management to assure that incompatible metallurgies are not mixed in the factory.
- The huge potential for mixed components from suppliers will drive validation and inspection costs throughout the factory.
- Rework operations have the potential to reduce the reliability of both Pb-free and SnPb solders

Acknowledgements

The following JCAA/JG-PP companies provided technical support and/or materials that made the assembly effort possible:

- ACI – Pb-free skill training for hand soldering
- BAE Systems Irving – factory time and labor expenses
- Boeing Phantom Works Seattle – technical support
- Florida CirTech, Inc. – materials
- Global Stencil – stencil services
- Heraeus – materials
- Kyzen – board cleaning after Pb-free wave solder
- MSL- translation of design data from Zuken Redac to GENCAD (Version 1.3).
- Rockwell-Collins – board design, procurement of parts and bare boards
- Senju Solder – materials
- Vitronics-Soltec – wave solder machine for Pb-free portion of assembly

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For additional JCAA/JG-PP Lead Free Solder Project information, please visit the following links:

<http://acqp2.nasa.gov/LFS.htm>

http://www.jgpp.com/projects_index.html

DEK 288 Solder Paste Screen Printer



Component Placement:



FUJI CP IV used for placement of capacitors and resistors.



FUJI IP3 used for fine pitch, BGAs, and other parts.



Solder Reflow: ABW Systems TSC-1210



Cleaning: Corpane Semi Aqueous Cleaner



X-Ray Evaluation- : Nicolet Imaging Systems 1410Hb



Hand Soldering



Rework (Removal and Replacement)



Wave Soldering: Delta-Max Machine



Wave Soldering @ Vitronics-Soltec: Delta-Wave Machine



BGA removal and replacement: AIR-VAC DRS24C

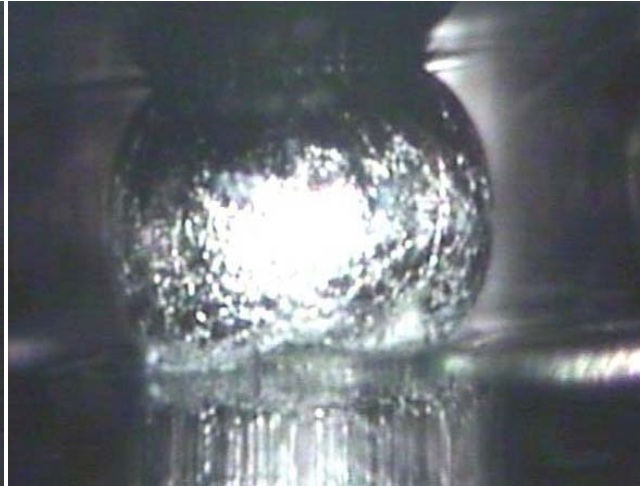


Comparison of SnPb BGAs

Soldered with SnPb, SnAgCu and SnAgCuBi



SN44 U56
soldered with SnPb.



SN110 U56
soldered with SAC.

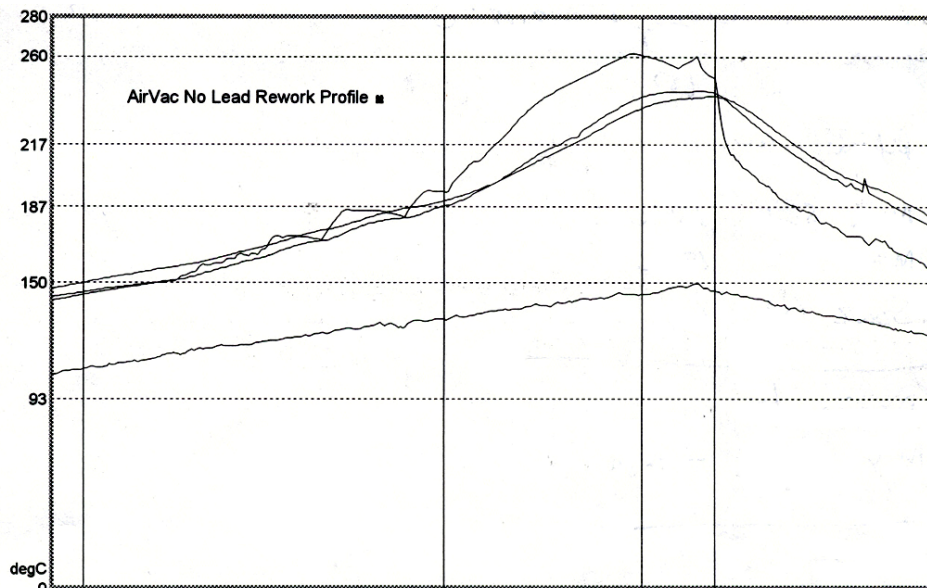
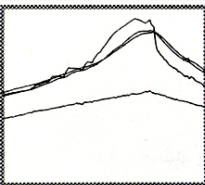


SN138 U56
soldered with SACB.

Pb-Free Rework Profile for BGA Replacement

M.O.L.E.® STATUS
Max Internal T: 27C
Battery: 4.893
Points: 389
Active: X234X6
Interval: 00:00:01.0
Date: 07/13/04
Time: 15:30:12 V08.58

Tool status box



Value	C1 = 00:00:14r	C2 = 00:02:52r	C3 = 00:04:19r	C4 = 00:04:50r	Units
<input type="checkbox"/> open					
<input checked="" type="checkbox"/> t/c2 top of U2 body	146	194	261	249	degC
<input checked="" type="checkbox"/> board surface	108	132	144	146	degC
<input checked="" type="checkbox"/> t/c4 under U2 BGA in pad	150	190	235	241	degC
<input type="checkbox"/> open					
<input checked="" type="checkbox"/> t/c6 topside under U2	144	187	241	242	degC

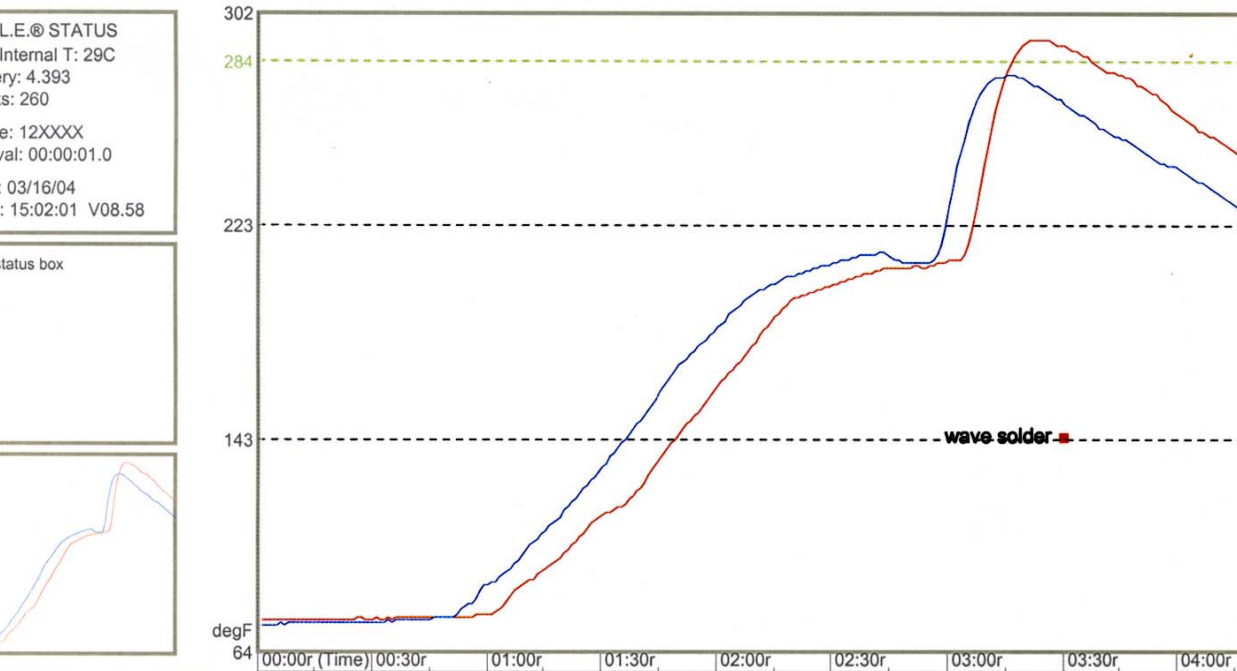
T Above Ref	Low = 150	Med = 217	Hi = 260	Cure Factor	Units
<input type="checkbox"/> open					
<input checked="" type="checkbox"/> t/c2 top of U2 body	00:05:44	00:01:41	00:00:14	0%	degC
<input checked="" type="checkbox"/> board surface	00:00:00	00:00:00	00:00:00	0%	degC
<input checked="" type="checkbox"/> t/c4 under U2 BGA in pad	00:06:14	00:01:37	00:00:00	0%	degC
<input type="checkbox"/> open					
<input checked="" type="checkbox"/> t/c6 topside under U2	00:05:43	00:01:36	00:00:00	0%	degC

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
<input type="checkbox"/> open							
<input checked="" type="checkbox"/> t/c2 top of U2 body	143	00:00:00r	262	00:04:13r	192.7	37.1	degC
<input checked="" type="checkbox"/> board surface	105	00:00:00r	149	00:04:41r	129.9	11.7	degC
<input checked="" type="checkbox"/> t/c4 under U2 BGA in pad	147	00:00:00r	241	00:04:46r	193.3	28.4	degC
<input type="checkbox"/> open							
<input checked="" type="checkbox"/> t/c6 topside under U2	141	00:00:00r	243	00:04:41r	190.9	31.4	degC

Device joint target = 243°C
 Device top max target = 260°C
 Board target = 110°C (process starting point)
 Board max = 150°C
 Reflow:
 ~97 seconds above 217°C
 ~75 seconds above 221°C
 ~44 seconds above 235°C
 Ball temperature 241°C
 Ramp rate 1.14°C/sec

AIR-VAC DRS24C.2D

'Rework & Manufactured-Control'



Typical SnPb Profile

Solder Pot Temperature =
250°C

Preheat Board T = 101°C

Peak Temperature = 144°C

Speed: 110 cm/min

Value	C1 = 00:00:51r	C2 = 00:01:42r	C3 = 00:02:33r	C4 = 00:03:24r	Units
k#1 trailing edge of pwb	77	130	202	292	degF
c#2 center of pwb	77	154	210	274	degF
T Above Ref	Low = 284	Med = 361	Hi = 446	Cure Factor	Units
k#1 trailing edge of pwb	00:00:21	00:00:00	00:00:00	0%	degF
c#2 center of pwb	00:00:00	00:00:00	00:00:00	0%	degF

SnPb Rework Profile

AIR-VAC DRS24C.2D for BGA Removal & Replacement

I.O.L.E.® STATUS

Max Internal T: 24C

Battery: 4.599

Points: 219

Active: XXX4X6

Interval: 00:00:01.0

Date: 04/01/04

Time: 14:48:19 V08.58

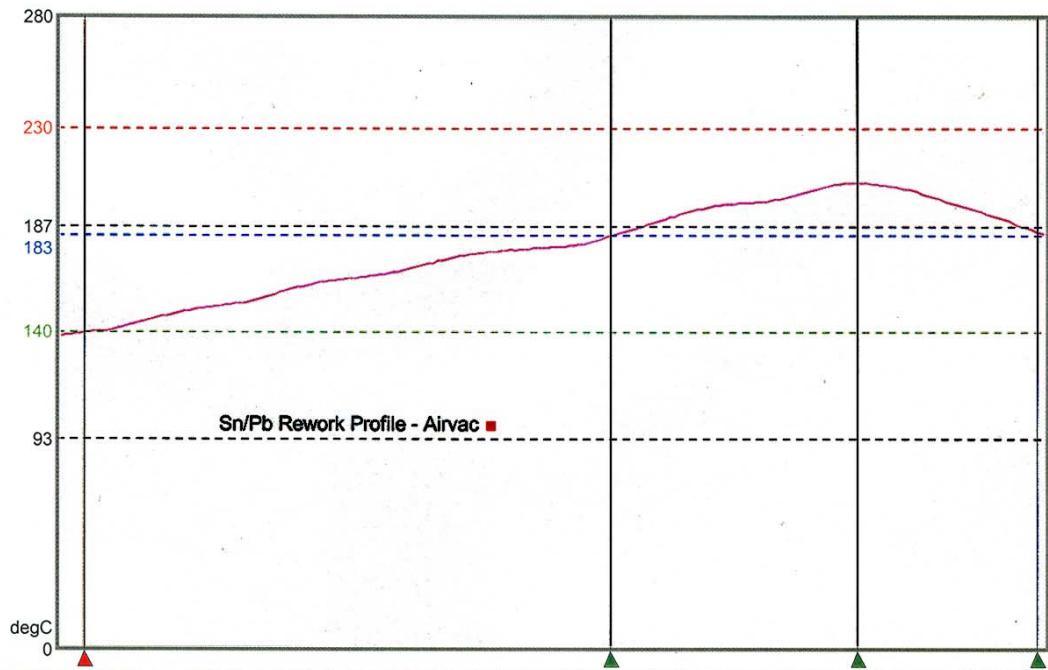
Pool status box

Sn/Pb base

Airvac

Rework profile

Auto ☐ Show Lag



Standard SnPb Rework Profile

Preheat = ~ 120 seconds
@140-183°C

Ball Peak temperature = 206°C

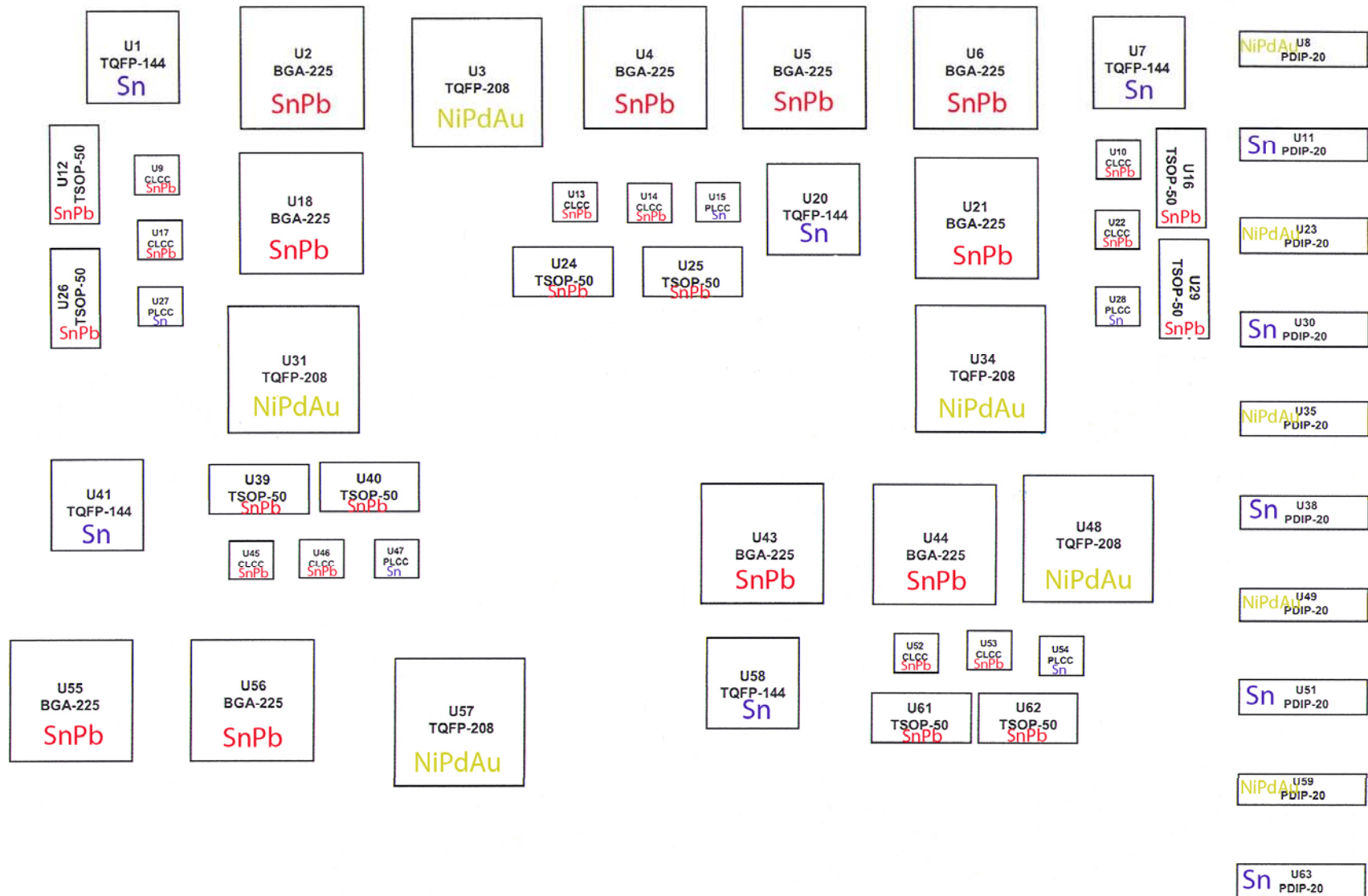
Time above reflow = 96 seconds

Ramp Rate = 2-3 °C/sec

Value	C1 = 00:00:06r	C2 = 00:02:02r	C3 = 00:02:56r	C4 = 00:03:35r	Units
open					
open					
open					
t/c4 under U2 BGA	140	183	206	184	degC
open					
t/c6 topside U2					

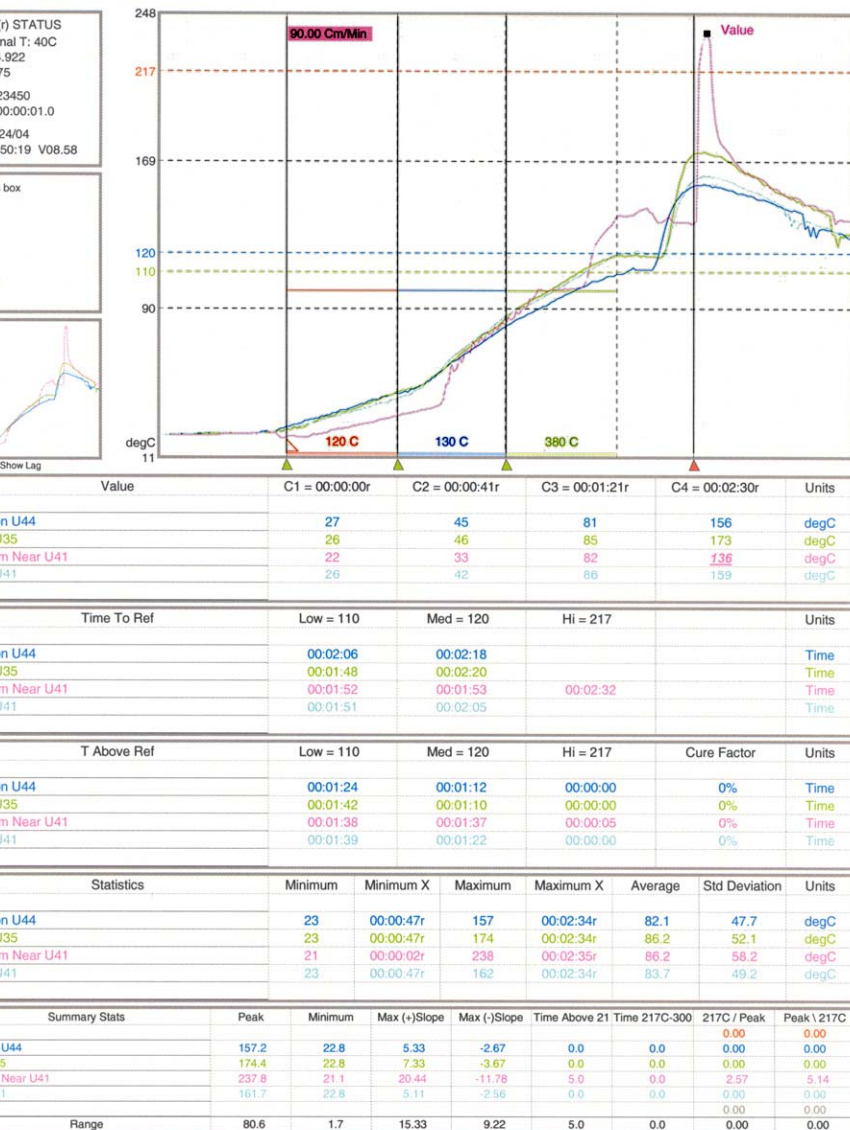
T Above Ref	Low = 140	Med = 183	Hi = 230	Cure Factor	Units
open					
open					
open					
t/c4 under U2 BGA	00:03:32	00:01:36	00:00:00	0%	degC
open					
t/c6 topside U2					

"Manufactured-Control" Test Vehicles



Immersion Ag PWB with **SnPb** Solder

Wave Solder Pb-Free Profile



SnCu

Solder Pot Temperature = 265°C

Preheat Board T = 134°C

Peak Temperature = 157°C

Speed: 90 cm/min

SAC

Solder Pot Temperature = 260°C

Preheat Board T = 136°C

Peak Temperature = 161°C

Speed: 90 cm/min

Profile provided by Vitronics-Soltec